VECTOR MESON PHOTOPRODUCTION IN THE SOFT DIPOLE POMERON MODEL FRAMEWORK

A. PROKUDIN [1,2,A], E. MARTYNOV[3,4,B] AND E. PREDAZZI[1,C]

[1] *Dipartimento di Fisica Teorica, Università Degli Studi Di Torino, Via Pietro Giuria 1, 10125 Torino, ITALY and Sezione INFN di Torino, ITALY*

[2] *Institute For High Energy Physics, 142281 Protvino, RUSSIA*

[3] *Bogolyubov Institute for Theoretical Physics, National Academy of Sciences of Ukraine, 03143 Kiev-143, Metrologicheskaja 14b, UKRAINE*

[4] *Institut de physique Bat B5-a Université de Liège Sart Tilman B-4000 Liège, BELGIQUE*

(A) E-mail: prokudin@to.infn.it (B) E-mail: e.martynov@guest.ulg.ac.be
(C) E-mail: predazzi@to.infn.it

Abstract. Exclusive photoproduction of all vector mesons by real and virtual photons is considered in the Soft Dipole Pomeron model. It is emphasized that being the Pomeron in this model a double Regge pole with intercept equal to one, we are led to rising cross-sections but the unitarity bounds are not violated. It is shown that all available data for $\rho, \omega, \varphi, J/\psi$ and Υ in the region of energies $1.7 \leq W \leq 250$ GeV and photon virtualities $0 \leq Q^2 \leq 35$ GeV^2 , including the differential cross-sections in the region of transfer momenta $0 \leq |t| \leq 1.6$ GeV^2, are well described by the model.

1. Introduction

A new precise measurement of J/ψ exclusive photoproduction by ZEUS [**?**] opens a new window in our understanding of the process and allows us to give more accurate predictions for future experiments.

The key issue of the dataset [**?**] is the diffractive cone shrinkage observed in J/ψ photoproduction which leads us to consider it a soft rather than pure QCD process so that we can apply the Soft Dipole Pomeron exchange [**?**] model.

The basic diagram is depicted in Figure 1; s and t are the usual Mandelstam variables, $Q^2 = -q^2$ is the virtuality of the photon.

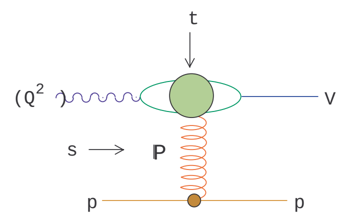

Figure 1. Photoproduction of a vector meson.

It is well known that high-energy representation of the scattering amplitude may be expressed as a sum over the the appropriate Regge poles in the complex j plane [**?**]

$$A(s,t)_{s\to\infty} \approx \sum_i \eta_i(t)\beta_i(t)(\cos\theta_t)^{\alpha_i(t)}, \tag{1}$$

where $\eta_i(t)$ is the signature factor and θ_t is the scattering angle in the t channel.

In the case of vector meson photoproduction we utilize the variable $z \sim \cos\theta_t$

$$z = \frac{2(W^2 - M_p^2) + t + Q^2 - M_V^2}{\sqrt{(t + Q^2 - M_V^2)^2 + 4M_V^2 Q^2}} \tag{2}$$

where $W^2 = (p+q)^2 \equiv s$, M_V is the vector meson mass, M_p is the proton mass.

Assuming vector meson dominance [**?**], the relation between the forward cross sections of $\gamma p \to Vp$ and $Vp \to Vp$ is given by

$$\frac{d\sigma}{dt}(t=0)_{\gamma p\to Vp} = \frac{4\pi\alpha}{f_V^2}\frac{d\sigma}{dt}(t=0)_{Vp\to Vp} \tag{3}$$

where the strength of the vector meson coupling $\frac{4\pi}{f_V^2}$ may be found from e^+e^- decay width of vector meson V

$$\Gamma_{V\to e^+e^-} = \frac{\alpha^2}{3}\frac{4\pi}{f_V^2}m_V \tag{4}$$

Using the property $\Gamma_{V\to e^+e^-}/ < Q_j^2 > \simeq const$ we can obtain the following approximate relations

$$m_\rho/f_\rho^2 : m_\omega/f_\omega^2 : m_\varphi/f_\varphi^2 : m_{J/\psi}/f_{J/\psi}^2 = 9:1:2:8 \tag{5}$$

which are in fairly good agreement with experimental measurements of decay widths [?].

We take into account these relations by introducing coefficients N_V (following to [?]) and writing the amplitude as $A_{\gamma p\to Vp} = N_C N_V A_{Vp\to Vp}$, where

$$N_C = 3\,; N_\rho = \frac{1}{\sqrt{2}}\,; N_\omega = \frac{1}{3\sqrt{2}}\,; N_\phi = \frac{1}{3}\,; N_{J/\psi} = \frac{2}{3}\,. \tag{6}$$

The amplitude of the process $Vp \to Vp$ may be written in the following form

$$A(z,t;M_V^2,\tilde{Q}^2) = I\!P(z,t;M_V^2,\tilde{Q}^2) + f(z,t;M_V^2,\tilde{Q}^2) + \ldots\,, \tag{7}$$

where, $\tilde{Q}^2 = Q^2 + M_V^2$.

$I\!P(z,t;M_V^2,\tilde{Q}^2)$ is the Pomeron contribution for which we use the so called dipole Pomeron which gives a very good description of all hadron-hadron total cross sections [?],[?]. Specifically, $I\!P$ is given by [?]

$$\begin{aligned} I\!P(z,t;M_V^2,\tilde{Q}^2) = i g_0(t;M_V^2,\tilde{Q}^2)(-iz)^{\alpha_{I\!P}(t)-1} + \\ i g_1(t;M_V^2,\tilde{Q}^2) ln(-iz)(-iz)^{\alpha_{I\!P}(t)-1}\,, \end{aligned} \tag{8}$$

where the first term is a single j-pole contribution and the second (with an additional $ln(-iz)$ factor) is the contribution of the double j-pole.

A similar expression applies to the contribution of the f-Reggeon

$$f(z,t;M_V^2,\tilde{Q}^2) = i g_f(t;M_V^2,\tilde{Q}^2)(-iz)^{\alpha_f(t)-1}. \tag{9}$$

It is important to stress that in this model the intercept of the Pomeron trajectory is equal to 1

$$\alpha_{I\!P}(0) = 1. \tag{10}$$

Thus the model does not violate the Froissart-Martin bound [?].

For ρ and φ meson photoproduction we write the scattering amplitude as the sum of a Pomeron and f contribution. According to the Okubo-Zweig rule, the f meson contribution should be suppressed in the production of the φ and J/ψ mesons, but given the present crudeness of the state of the art, we added the f meson contribution in the φ meson case.

For ω meson photoproduction, we include also π meson exchange (see also the discussion in [?]), which is needed in the low energy sector given that we try to describe the data for all energies W. Even though we did not expect it, the model describes well the data down to threshold.

In the integrated elastic cross section

$$\sigma(z,M_V^2,\tilde{Q}^2)_{el}^{\gamma p\to Vp} = 4\pi \int_{t_-}^{t_+} dt |A^{\gamma p\to Vp}(z,t;M_V^2,\tilde{Q}^2)|^2\,, \tag{11}$$

the upper and lower limits

$$2t_{\pm} = \pm\frac{L_1 L_2}{W^2} - (W^2 + Q^2 - M_V^2 - 2M_p^2) + \frac{(Q^2 + M_p^2)(M_V^2 - M_p^2)}{W^2}, \quad (12)$$

$$L_1 = \lambda(W^2, -Q^2, M_p^2), \qquad L_2 = \lambda(W^2, M_V^2, M_p^2), \quad (13)$$

$$\lambda^2(x, y, z) = x^2 + y^2 + z^2 - 2xy - 2yz - 2zx, \quad (14)$$

are determined by the kinematical condition $-1 \le \cos\theta_s \le 1$ where θ_s is the scattering angle in the s-channel of the process.

For the Pomeron contribution (9) we use a nonlinear trajectory

$$\alpha_{I\!P}(t) = 1 + \gamma(\sqrt{4m_\pi^2} - \sqrt{4m_\pi^2 - t}\,), \quad (15)$$

where m_π is the pion mass. Such a trajectory was utilized for photoproduction amplitudes in [**?**], [**?**] and its roots are very old [**?**].

For the f-meson contribution for the sake of simplicity we use the standard linear Reggeon trajectory

$$\alpha_{I\!R}(t) = \alpha_{I\!R}(0) + \alpha'_{I\!R}(0)\, t\,. \quad (16)$$

In the case of nonzero virtuality of the photon, we have a new variable in play $Q^2 = -q^2$. At the same time, the cross section σ_L is nonzero.

2. The Model

For the Pomeron residues we use the following parametrization

$$g_i(t; M_V^2, \tilde{Q}^2) = \frac{g_i}{Q_i^2 + \tilde{Q}^2} exp(b_i(t; \tilde{Q}^2))\,, \quad (17)$$
$$i = 0, 1\,.$$

The slopes are chosen as

$$b_i(t; \tilde{Q}^2) = \Big(b_{i0} + \frac{b_{i1}}{1 + \tilde{Q}^2/Q_b^2}\Big)(\sqrt{4m_\pi^2} - \sqrt{4m_\pi^2 - t}\,)\,, \quad (18)$$
$$i = 0, 1\,,$$

to comply with the previous choice (15) and analyticity requirements [**?**]. The Reggeon residue is

$$g_{I\!R}(t; M_V^2, \tilde{Q}^2) = \frac{g_{I\!R} M_p^2}{(Q_{I\!R}^2 + \tilde{Q}^2)\tilde{Q}^2} exp(b_{I\!R}(t; \tilde{Q}^2))\,, \quad (19)$$